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Nucleon resonance decay by the $K^0\Sigma^+$ channel: Preliminary results

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Abstract. The strange meson production on a proton target in the $K^0\Sigma^+$ channel is sensitive to nucleon resonance contributions. The K^0 production on a deuteron target can provide information on the hyperon–nucleon final-state interaction. The experiments $\gamma p \to K^0\Sigma^+$ and $\gamma d \to K^0\Sigma^+ n$ have been carried out at the ELSA facility at Bonn. In this paper, we report the preliminary results of both experiments.

Keywords. Photonuclear reactions; nucleon resonances; hyperon–nucleon interaction.

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1. Introduction

The spectrum of baryon excitations is not yet well described on the basis of QCD. Theoretical studies of baryon resonances take into account the internal degrees of freedom of the flavor triplet of light u, d and s quarks. Models differ, however, in the treatment of the spatial dynamics which provides different modes of excitation. A stringent test of hadron models requires a systematic study of baryon excitations and their respective decay modes in the mass region of 1 GeV above the nucleon mass and beyond. Recent predictions in a quark-pair creation model [1] or a collective string-like three-quark model [2] revealed substantial decay branches into $K\Lambda$ and $K\Sigma$ final state. Kaon production experiments are an important tool to establish or disprove 'missing' resonances and thus to determine the relevant degrees of freedom of quark models. The observed η decay branches of the S_{11} baryon resonances could find an explanation in mixing with other exotic resonances of pentaquark nature or with quasi-bound S_{11} states near the $K\Lambda$ or $K\Sigma$ threshold. The precise threshold behavior of the $K^0\Sigma^+$ decay, accessible via the multiphoton–proton decay channel may provide a signature of an additional S_{11} resonance.

The associated production of kaons and hyperons in photonuclear and the pp reactions is an important source of information on the hyperon–nucleon (YN) interaction through strong contributions from the final-state interaction (FSI). Until now, only scarce experimental information is available from hyperon scattering

($\Lambda p \to \Lambda p$, $\Sigma^{\pm}p \to \Sigma^{\pm}p$), charge exchange ($\Sigma^- p \to \Sigma^0 p$) and inelastic processes ($\Sigma^- p \to \Lambda n$, $\Lambda p \to \Sigma^0 p$). Some additional information is available from hypernuclei and K-induced production processes ($K^- d \to YN\pi$).

Quasi-free kaon production on the deuteron was suggested in [3] in order to obtain information on the YN interaction. A calculation [4] including the FSI predicts a significant enhancement of the cross-section at the ΣN threshold. As compared to the plane-wave result without FSI, the YN interaction has a significant effect near the ΣN threshold at $E_\gamma = 1.49$ GeV, where the cross-section is increased by a factor of 5. No data are available at all for the Σn channel. The final-state interaction is essential only at small relative momenta between Y and N. Therefore, it would be very interesting to look for FSI in $\gamma d \to K^0\Sigma^+ n$ channel at the low relative momentum $k = |\vec{p}_{\Sigma^+} - \vec{p}_n|$.

In this paper, we will discuss the first results from the hydrogen target and address the deuteron target data afterwards.

2. The experiment

The experiment has been performed at the Elektronen-Stretcher-Anlage (ELSA) facility in Bonn, which can provide electron beams up to 3.5 GeV. The bremsstrahlung photon beam was obtained by passing the electron beam through a Cu radiator. The photon beam was made incident on a liquid hydrogen or a liquid deuterium target. The hyperon- and meson-decay photons have been measured by the Crystal-Barrel (CB) in combination with the TAPS spectrometer. CB consist of 1290 CsI(Tl) crystals read out with photodiodes, covering the polar angles from 30° to 168°. TAPS was positioned as a forward wall which covers the angles from 5° to 30°. TAPS consists of 528 hexagonally-shaped BaF_2 crystals fitted with photomultiplier tubes. The performance of TAPS is discussed in more detail in [5]. The CB-TAPS set-up covers almost 95% of the 4π solid angle and allows to measure the channels involving several neutral particles in the final state.

The charged particles were detected by three layers of scintillating fibers in the inner detector surrounding the liquid hydrogen (deuterium) target. The forward going charged particles were signalled by 5 mm-thick plastic scintillators from the VETO detector in front of TAPS. A first level trigger has been made by requiring two hits in TAPS or one hit in TAPS along with one or more hits in CB. Before and after the data taking runs the signals from cosmic muons were measured providing a relative calibration. The energy calibration was achieved by reconstructing the 2γ invariant mass for TAPS and CB spectrometers. By iteratively adjusting the gains of each detector, the pion and eta mass peaks were fitted. For the time calibration relative coincidence between 2 hits in TAPS were observed.

3. Analysis of $\gamma p \to K^0\Sigma^+$ channel

The channel of interest, $\gamma p \to K^0\Sigma^+ \to 3\pi^0 p \to 6\gamma p$ has 6γs and a proton in the final state. All the events with this final state have been selected and kinematically fitted in order to improve the invariant mass resolution. The kinematical fit includes constraints on the momentum and energy balances (4 equations) and the π^0 masses (3 equations). The information about energy and position of all photons and the position of the proton was provided to the fit. The energy of the proton was calculated from the kinematical fit. A 10% cut was made on the confidence level. In order to see the effect of the kinematical fit on the mass resolution, another channel with the same final state, $\gamma p \to \eta p \to 3\pi^0 p \to 6\gamma p$, has been studied. The η mass resolution before the kinematical fit, $\sigma = 21$ MeV, improved to $\sigma = 9$ MeV after the kinematical fit. However, the number of ηs remains same.

All the events with invariant mass different from M_η were selected for further analysis. The K^0 and Σ^+ were reconstructed for the remaining events. The two-dimensional spectrum for $\pi^0\pi^0$ and $\pi^0 p$ invariant mass is shown in figure 1 (right). The background is fitted by a polynomial in both cases. The mass resolution for K^0 and Σ^+ was observed to be 16 MeV and 12 MeV, respectively. About 7000 K^0s were found in 1000 h of beam time.

To calculate the cross-sections, the flux normalisation was obtained from the well-known $\gamma p \to \eta p$ channel measured by CB at ELSA [6]. Comparing the total cross-section with the same channel in our data set, an overall normalisation factor consisting of the luminosity and acceptance effects was determined. This factor is subsequently applied to obtain the total cross section for the $\gamma p \to K^0\Sigma^+$ channel. Simulations show that the acceptance for reactions on the proton and the deuteron is similar. The results for the proton target are shown in figure 2. The results are compared with a recent analysis of the SAPHIR experiment from [7] revealing a good agreement in general. Also available are the angular distributions and polarisation observables.

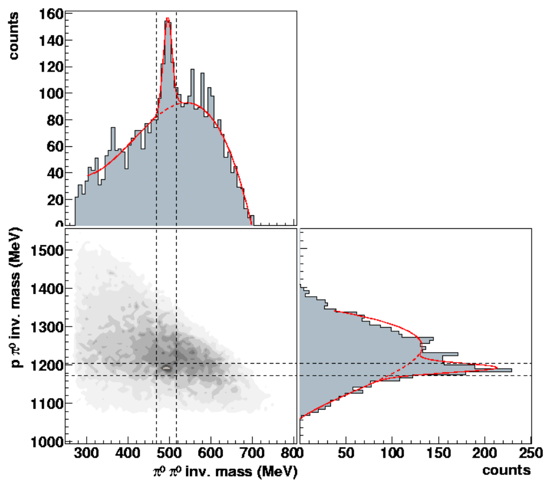

Figure 1. For the $\gamma p \to K^0\Sigma^+$ reaction, the $\pi^0\pi^0$ invariant mass is shown in dependence of the $\pi^0 p$ invariant mass. The $\pi^0\pi^0$ invariant mass is plotted after a cut on the Σ^+ mass. Similarly, the $\pi^0 p$ invariant mass is plotted after a cut on the K^0 mass.

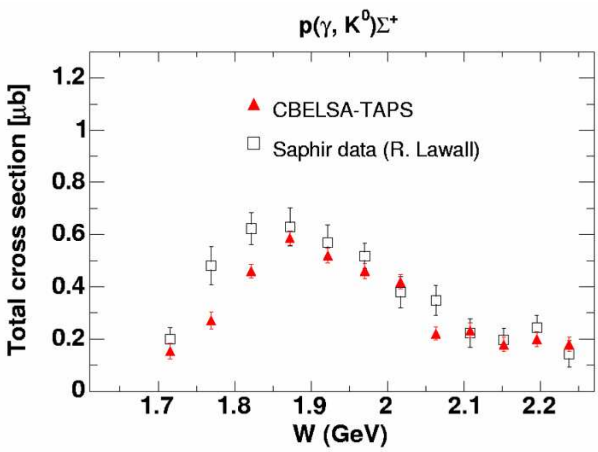

Figure 2. The $K^0\Sigma^+$ total cross-section for photoproduction on the proton. The triangles are the preliminary results from CB/TAPS, and open squares are the results from the recent analysis of SAPHIR data.

4. Analysis of $\gamma d \rightarrow K^0\Sigma^+ n$ channel

The channel $\gamma d \rightarrow K^0\Sigma^+ n \rightarrow 3\pi^0 pn \rightarrow 6\gamma pn$ has an extra neutron in the final state. Since the reaction occurs on the proton inside the deuteron, the neutron acts as a spectator. The outgoing neutron remains undetected in our detector set-up. The events with $3\pi^0$s and a proton are selected for further analysis. The neutron energy and momentum were calculated from kinematical fitting. In the kinematical-fitting procedure the energies and momenta of the detected photons and the proton were allowed to vary within the detector resolution. The pion mass, total energy and momentum balance were used to constrain the kinematic equations. The 10% confidence level cut has been applied.

The background channel with the same final state, $\gamma d \rightarrow \eta pn \rightarrow 3\pi^0 pn \rightarrow 6\gamma pn$, has been studied in order to check the quasi-free η production on the proton in the deuteron. For the same channel the $3\pi^0$ invariant mass is plotted in figure 3 after the cut on the confidence level. An η mass resolution of $\sigma = 10$ MeV has been achieved which is in a good agreement with the value obtained for the $\gamma p \rightarrow \eta p$ data.

Since the neutron was assumed a spectator in our reaction, its momentum should follow the momentum distribution inside the deuteron. The neutron momentum distribution is plotted in figure 3 after the 10% cut on kinematic fit and η selection. It shows a peak around 65 MeV/c which is due to quasi-free η production. The distribution has a tail which can be a signature of FSI. More investigation is needed in order to achieve a complete description of the neutron momentum distribution.

The first result for the K^0 signal in the data set for the deuteron target is shown in figure 4 for 5% of our data set. The invariant mass has been plotted in the same way, using a cut on Σ^+ mass, as discussed earlier. A clear peak can be observed at the K^0 mass on top of the background. The background was fitted by a polynomial. The Gaussian function was fitted to the peak. A mass resolution of 17 MeV has

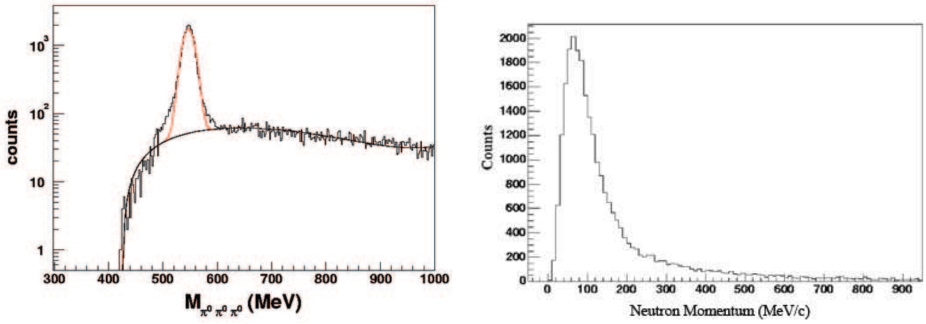

Figure 3. The $3\pi^0$ invariant mass for the $\gamma d \to \eta pn \to 3\pi^0 pn \to 6\gamma pn$ channel (left). The neutron momentum distribution after the kinematic fit and the cut on the η mass (right).

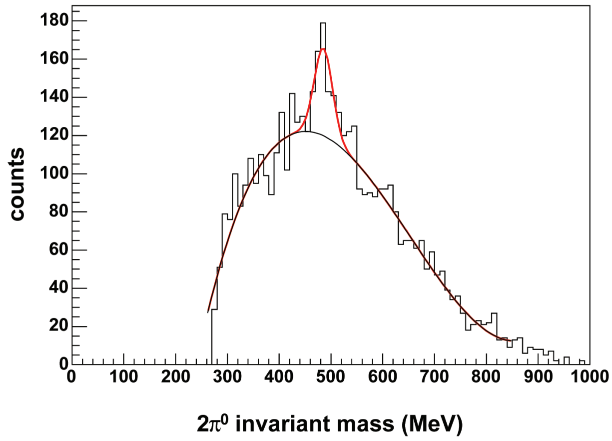

Figure 4. The $\pi^0\pi^0$ invariant mass spectrum after a cut on the Σ^+ mass.

been observed, which is almost the same as that for the $\gamma p \to K^0\Sigma^+$ reaction. The total number of K^0 for the complete data set will be approximately 4000 for the quasi-free reaction channel.

In the next step we will determine the cross-section for the $K^0\Sigma^+n$ channel and analyse the angular distribution and kaon production cross-section at low and high relative momentum $k = |\vec{p}_{\Sigma^+} - \vec{p}_n|$ in order to differentiate between FSI and non-FSI reactions.

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